

# Chapter 19

## Lecture Outline\*

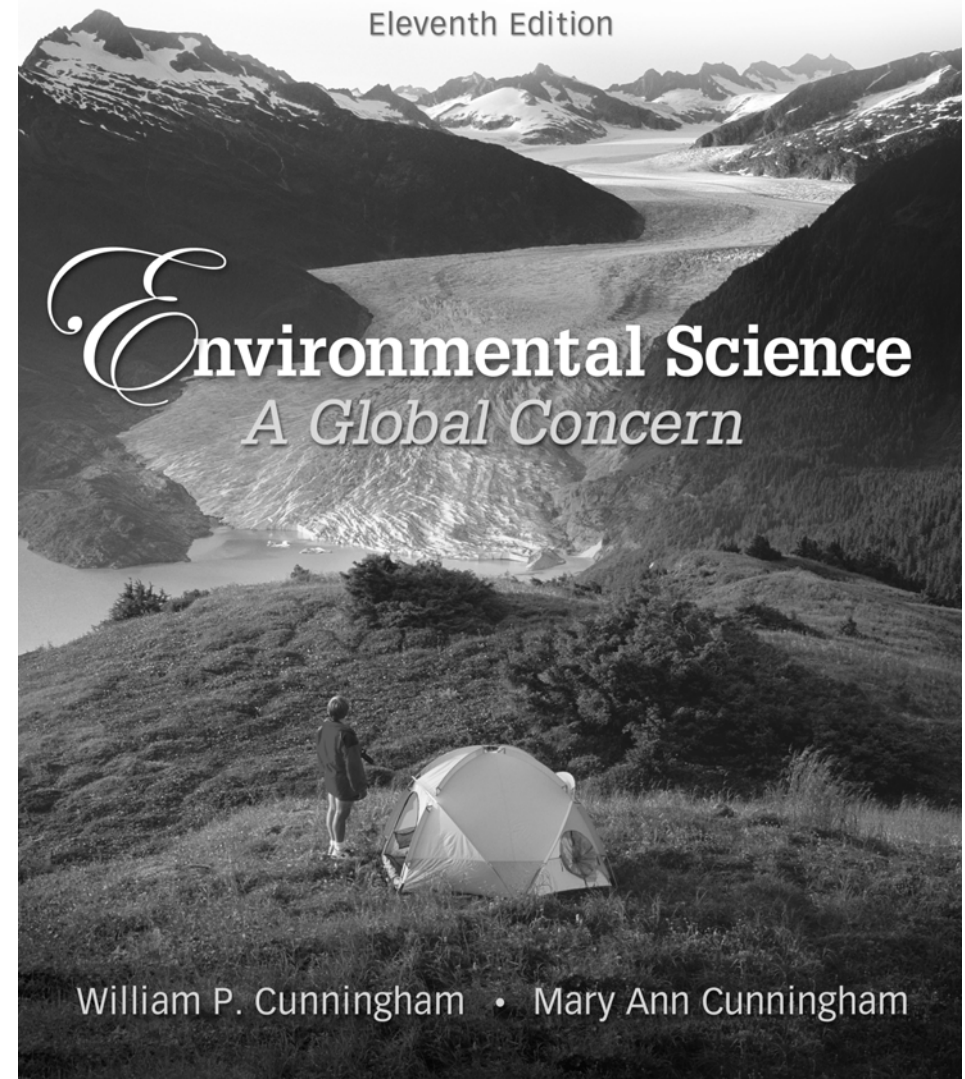
William P. Cunningham

*University of Minnesota*

Mary Ann Cunningham

*Vassar College*

**\*See PowerPoint Image Slides for all  
figures and tables pre-inserted into  
PowerPoint without notes.**



# Conventional Energy

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# Outline

- What is Energy?
- How Energy Is Used
- Coal
- Oil
- Natural Gas
- Nuclear Power
  - ❖ Nuclear Fission
  - ❖ Reactors Types
  - ❖ Waste Management
  - ❖ Nuclear Fusion

## \*How Do We Measure Energy?

- Work - application of force over distance
  - (measured in joules)
- Energy - the capacity to do work
- Power - rate at which work is done
  - (measured in watts)
  - ❖ Newton - force needed to accelerate 1 kg 1 meter per second
  - ❖ Joule - amount of work done when a force of 1 newton is exerted over 1 meter
  - ❖ Watt –one joule per second

## \*Measuring Energy

- Lighting a standard 100 watt light bulb for 10 hours uses 1000 watt-hours of power or 1 kilowatt-hour.
- The average American home uses 11,000 kilowatt-hours of electricity per year.

# Typical Energy Usage

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**Table 19.2 Energy Uses**

Uses	kWh/year*
Computer	100
Television	125
100 W light bulb	250
15 W flourescent bulb	40
Dehumidifier	400
Dishwasher	600
Electric stove/oven	650
Clothes dryer	900
Refrigerator	1100

\*Averages shown; actual rates vary greatly.

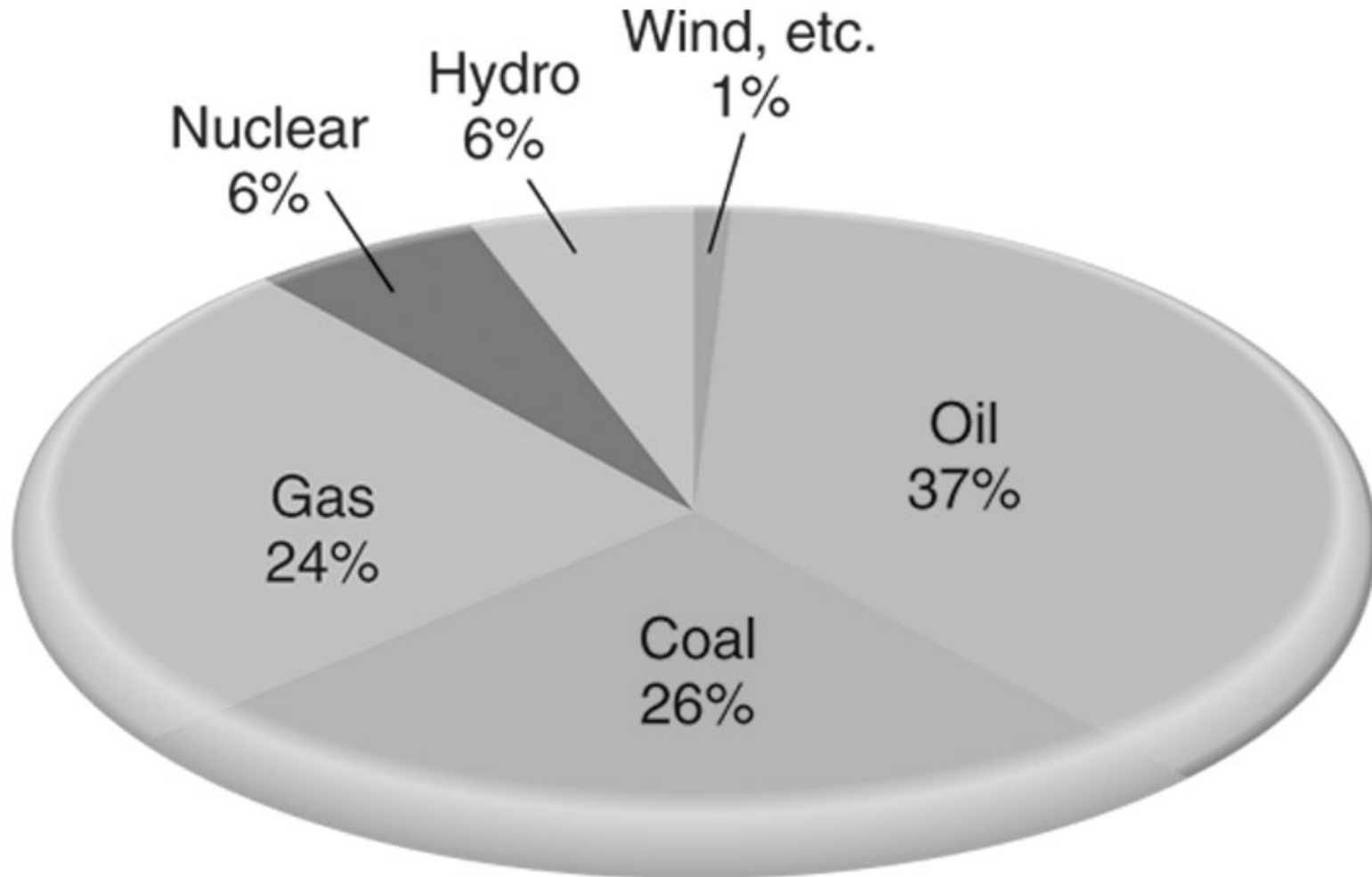
**Source:** U.S. Department of Energy.

## \*Fossil Fuels Supply Most Energy

- Currently, fossil fuels supply 87% of the world's commercial energy needs.
  - ❖ Oil makes up 37% of this total
  - ❖ Nuclear power makes up 6%
  - ❖ Hydropower makes up 6%
  - ❖ Wind and solar make up only about 1%

# Worldwide Commercial Energy Production

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# Per Capita Consumption

- Richest countries have consumed nearly 80% of all commercial energy despite having only 20% of population. This is changing.
  - ❖ India's oil consumption has doubled since 1992. China went from self-sufficiency to the world's second largest oil importer.
  - ❖ Many countries are competing for a limited resource.
  - ❖ Americans use 6.5 billion gal, but produce only 2.5 billion gal. We import the rest, which is becoming increasingly problematic.

# Per Capita Energy Use

- Each person in a rich country consumes nearly as much oil in a day as the poorest people in the world consume in a year.
- Some countries such as Norway, Denmark and Japan have a much higher standard of living than the U.S. but use half as much energy.
- This suggests that we could keep our standard of living while conserving energy.

# Where Do We Get Energy Currently?

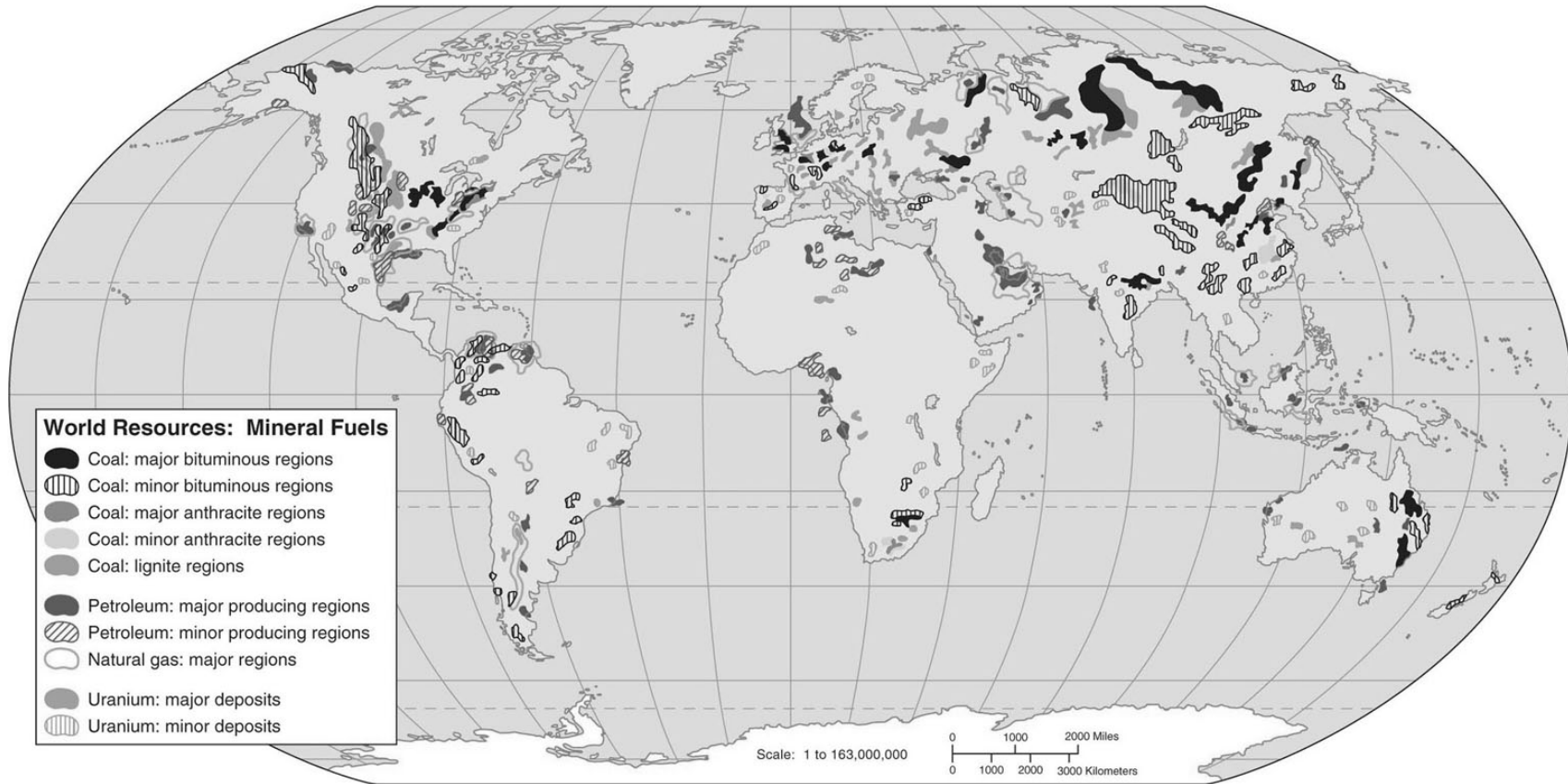
- Until 1947, the U.S. was the largest exporter of oil in the world. Reserves are now depleted and U.S. is the largest oil importer in the world.
- We depend on foreign sources for 75% of our supply.
  - ❖ Largest proportion of that comes from Canada and Saudi Arabia followed by Mexico and Venezuela

# How Energy Is Used

- Largest share of energy used in the U.S. is consumed by industry (33%). In some cases, is it not used for energy but is made into plastics, fertilizers, lubricants, etc.
- Residential and commercial buildings use 20%, mostly for heating, cooling and light .
- Transportation consumes about 28% of all.
- About half the energy in fuels is lost during conversion, shipping and use, and huge amounts of pollution are released.

# Distribution of World Mineral Fuels

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## \*Coal

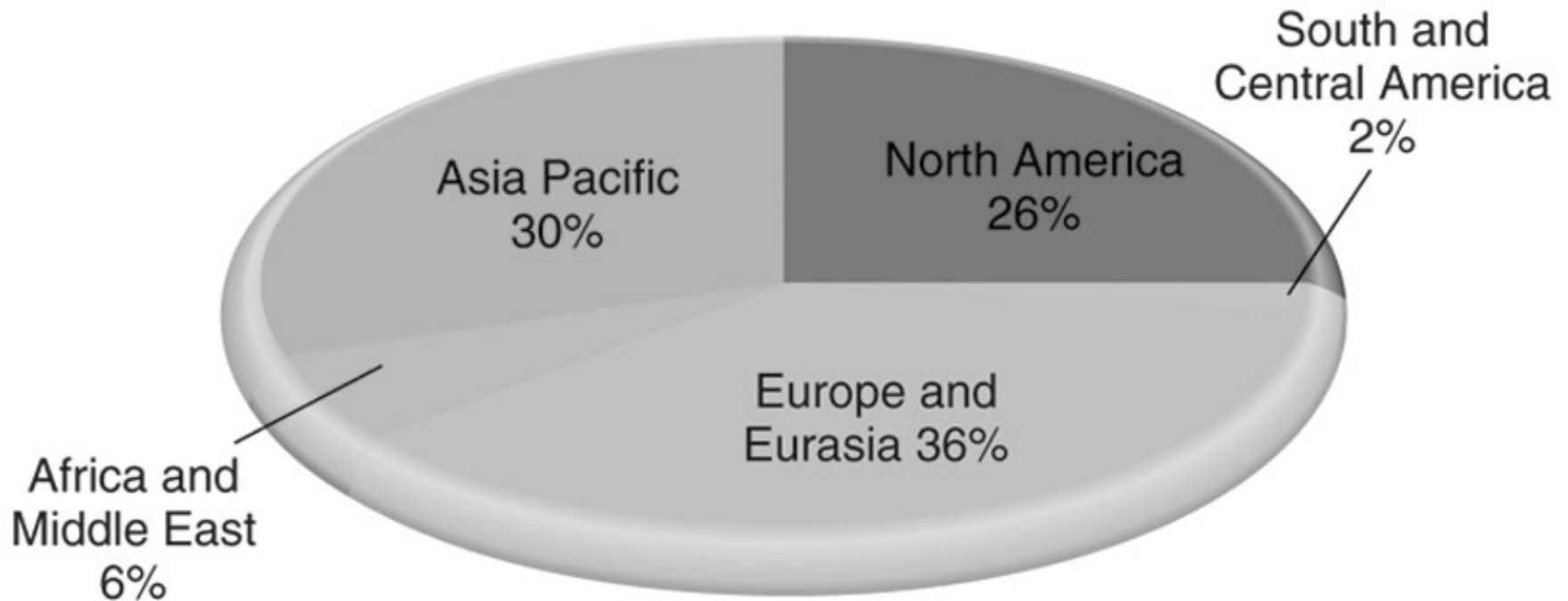
- Fossilized plant material preserved by burial in sediments and compacted and condensed by geological forces into carbon-rich fuel.
  - ❖ Most laid down during Carboniferous period (286 million to 360 million years ago).
  - ❖ Because coal took so long to form, it is essentially a nonrenewable resource.

# Coal Resources Are Vast

- Resources and Reserves
  - ❖ World coal deposits are ten times greater than conventional oil and gas resources combined.
  - ❖ Proven reserves - have been mapped, measured and shown to be economically recoverable. Proven reserves of coal worldwide will last about 200 years at present rates of consumption.
  - ❖ That could increase to thousands of years if estimates of unknown reserves are included.

# Proven-In-Place Coal Reserves

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# Coal Mining Is Dirty and Dangerous

- Mining
  - ❖ Between 1870 and 1950, more than 30,000 American coal miners died of accidents and injuries in Pennsylvania alone.
    - Thousands have died of respiratory diseases.
      - Black Lung Disease - inflammation and fibrosis caused by accumulation of coal dust in the lungs or airways
  - ❖ China currently has the most dangerous mines, with 91,172 killed in mining accidents in 2008.

# Coal Mining Is Destructive

- Strip mining is cheaper and safer than underground mining.
  - ❖ Often makes land unfit for other use
  - ❖ Acid drainage damages streams.
  - ❖ Mountaintop removal, practiced in Appalachia, causes streams, farms and even whole towns to be buried under hundreds of meters of toxic rubble.

# Mountain Top Removal

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# Burning Coal Releases Pollutants

- Coal burning releases radioactive and toxic metals into the atmosphere.
  - Coal combustion is responsible for 25% of all atmospheric mercury pollution in the U.S.
- Ash from coal combustion is stored in open storage ponds which sometime experience catastrophic failures causing millions of dollars in damages and polluting local water supplies.
- Coal burning releases sulfur and nitrogen oxides, particulates, and carbon dioxide which contribute to acid rain, air pollution, and global warming.

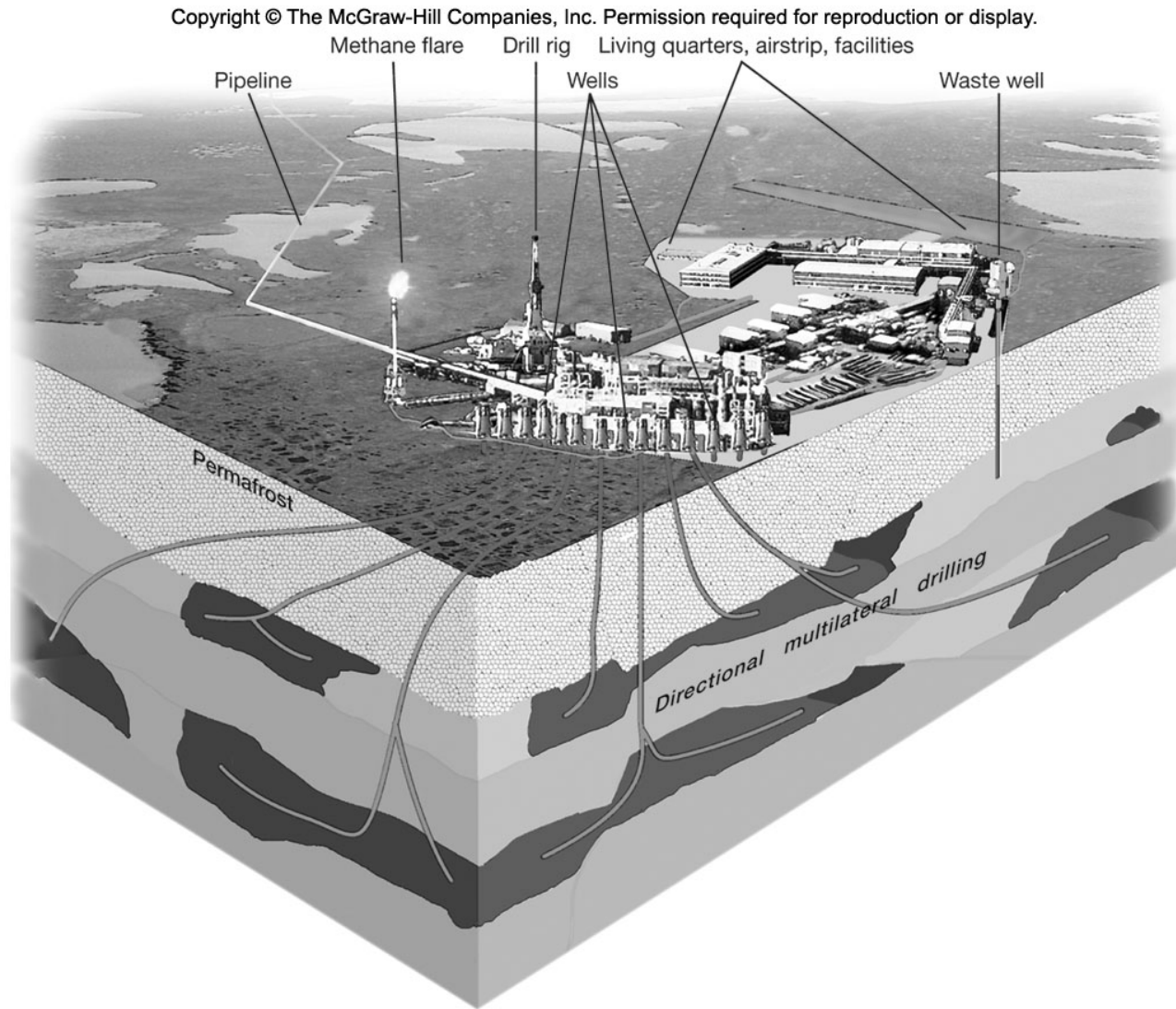
## \*Clean Coal Technology Could Be Useful

- New technology (such as integrated gasification combined cycle) captures CO<sub>2</sub> as well as removing sulfur and mercury. This would cut down on emissions.
- Carbon dioxide could be sequestered by pumping it into deep geologic formations, which could also enhance oil recovery.
- Coal to liquid technology - converts coal to liquid fuel. One of the worst alternatives as there are massive carbon dioxide releases
- Flex-Fuel Boilers – coal can be mixed with biomass fuels to produce energy with less carbon dioxide emissions.

## \*Oil

- Petroleum is formed in a similar way to oil - Organic material buried in sediment and subjected to high pressure and temperature.
  - ❖ An “Oil pool” is usually composed of individual droplets or a thin film permeating spaces in porous sandstone (like water in a sponge)
  - ❖ Ultra deep wells are possible (40,000 ft)
  - ❖ Directional drilling allows well heads to travel horizontally up to 6 km away to reach the oil.
  - ❖ We recover about 40% of oil in a formation before it becomes uneconomical to continue.

# Directional Drilling



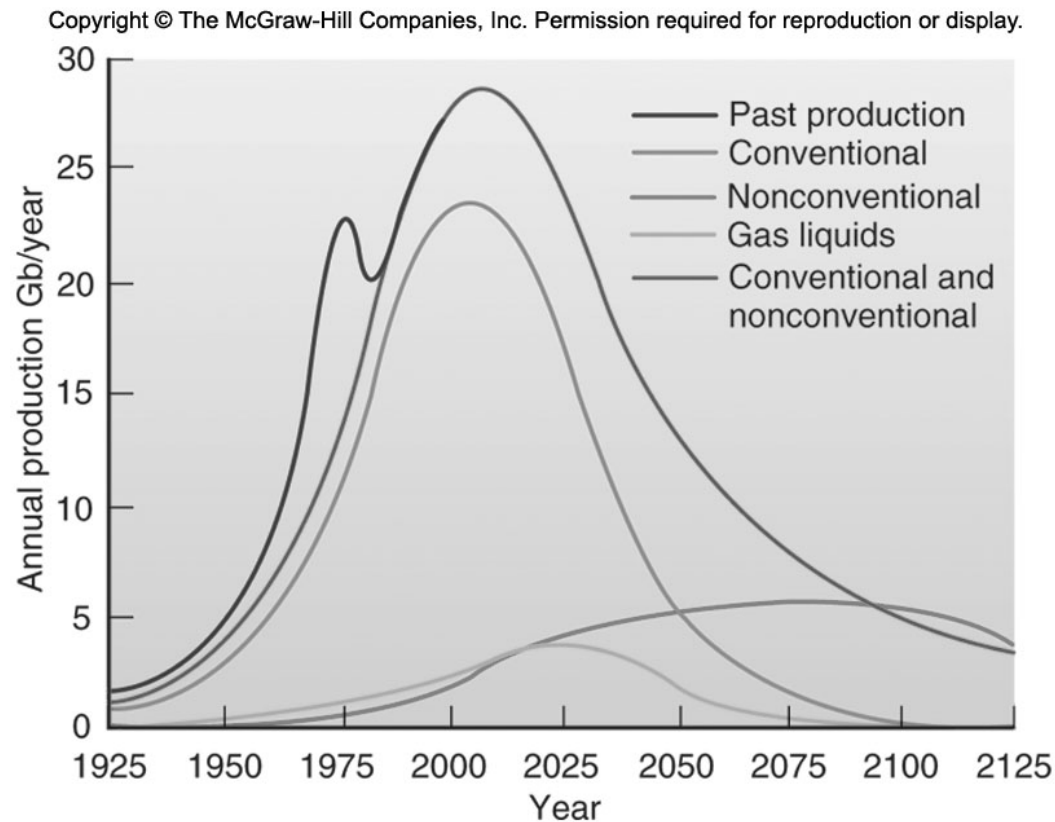
# Oil Resources Aren't Evenly Distributed

- Resources and Reserves
  - ❖ Total amount of oil in the world is estimated at 4 trillion barrels. (Half is thought to be ultimately recoverable.)
  - ❖ Proven reserves as of 2006 are enough to last 40 years; U.S. reserves would last 4 years if we stopped importing.
  - ❖ The “Greater Middle East” contains 91% of proven, economically-recoverable oil.
    - As oil becomes depleted and prices rise, it will likely become more economical to find and bring other more difficult reserves to light.



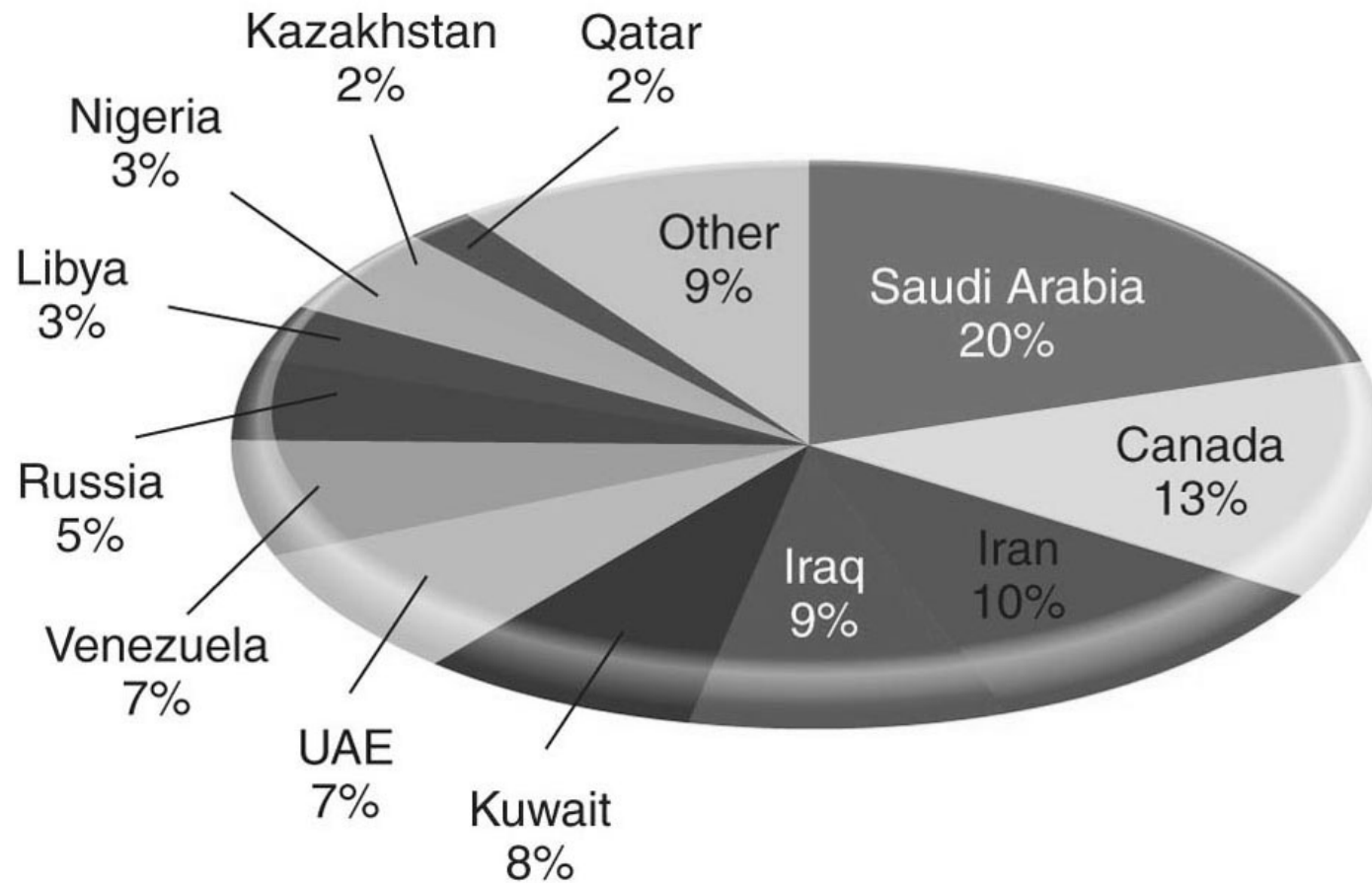
# Oil

- Many geologists expect that oil production will peak within 10 years and then decline.



# \*Locations of Proven Oil Reserves

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Source: Data from DOE, 2008

# Like Other Fuels, Oil Has Negative Impacts

- Disrupts wildlife and plants
  - ❖ Drilling in Arctic National Wildlife Refuge would produce 7 billion barrels of oil total (~1 year's supply), while disrupting crucial caribou calving grounds.
- Burning oil produces carbon dioxide, nitrogen oxides and ozone.
- Every year billion tons of oil are shipped in ocean tankers or through pipelines.
  - ❖ In 1978, the Amoco Cadiz ran aground contaminating 350 km of French coastline.
  - ❖ Leaks in the Alaskan Pipeline have spilled over 1 million liters on the tundra.

# Alaskan Pipeline

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## \*Oil Shales and Tar Sands

- Oil shales and tar sands contain 10X as much as conventional reserves.
- Tar sands are composed of sand and shale particles coated with bitumen, a viscous mixture of long chain hydrocarbons. They have to be mixed with steam to extract the bitumen, which is then refined.
- Process creates toxic sludge, releases greenhouse gases, contaminates water, and destroys boreal forest in Canada where most of reserves are.

# Oil Shales and Tar Sands

- Oil shales occur in western U.S.
- Might yield several trillion gallons of oil
- Oil shale is sedimentary rock rich in kerogen. Kerogen can be heated and extracted.
- Mining is expensive, uses vast quantities of water (which is a scarce resource in the west), contributes to air and water pollution, and produces huge quantities of waste.

# Natural Gas

- World's third largest commercial fuel
  - ❖ 24% of global energy consumption
  - ❖ Composed primarily of methane
  - ❖ Produces half as much CO<sub>2</sub> as equivalent amount of coal
  - ❖ Most rapidly growing energy source
    - LNG -Gas is liquefied to ship it by ocean. A ship explosion would be equivalent to a medium sized atomic bomb.

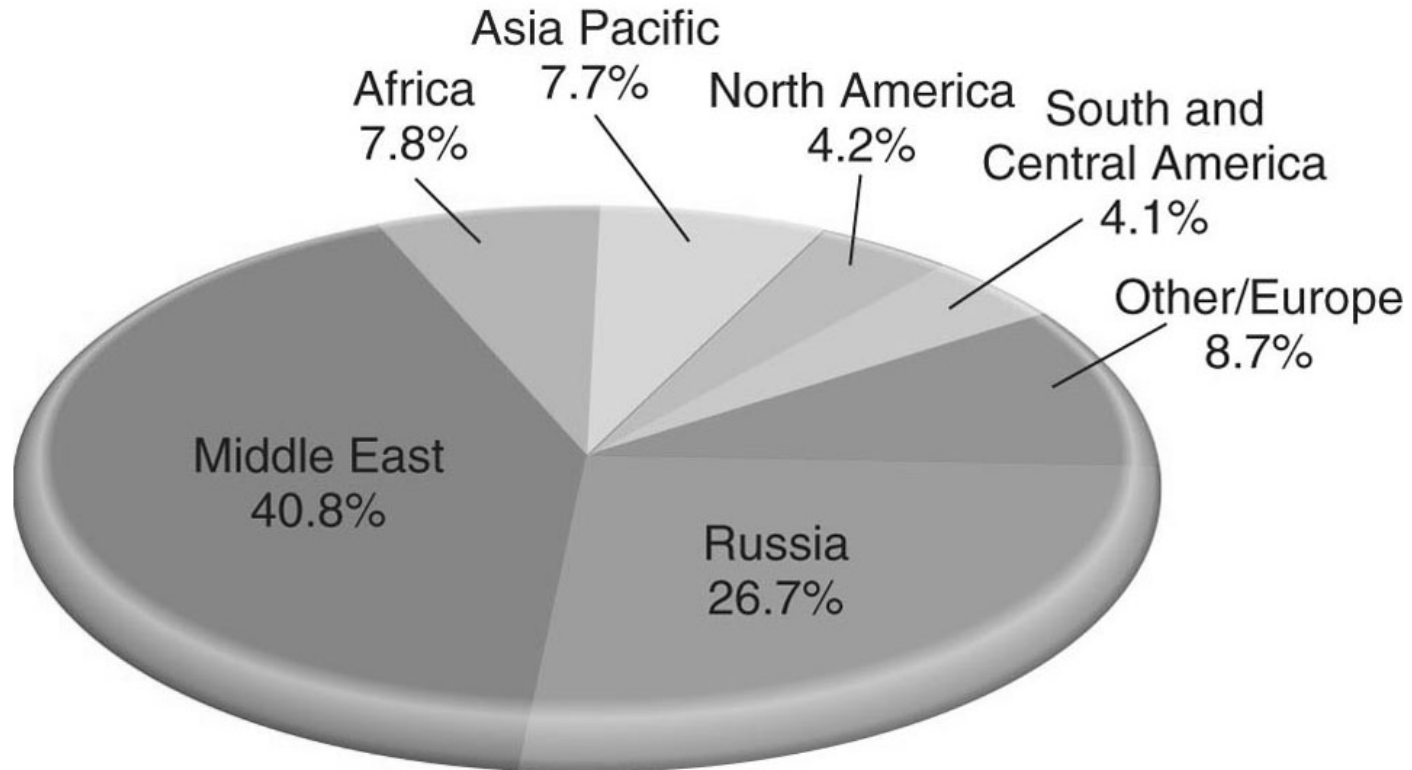
# Natural Gas

- Resources and Reserves
- Two thirds of reserves are in Middle East and former Soviet Union.
- At current rates of use, we have a 60 year supply worldwide.
- U.S. has 3% of world reserves, or about a 10 year supply but it is estimated that there is twice as much that could ultimately be tapped.
- Methane can be extracted from coal seams.



# Proven Natural Gas Reserves By Region

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Source: British Petroleum, 2006

## \*Unconventional Gas Sources

- Methane hydrate - Small individual molecules of natural gas trapped in a crystalline matrix of frozen water. Found in arctic and beneath ocean.
  - ❖ Thought to hold 10,000 gigatons of carbon, or twice as much as combined amount of all traditional fossil fuels
    - Difficult to extract, store, and ship
- Methane could be extracted from garbage, manure.

# Nuclear Power Plants

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# Nuclear Power

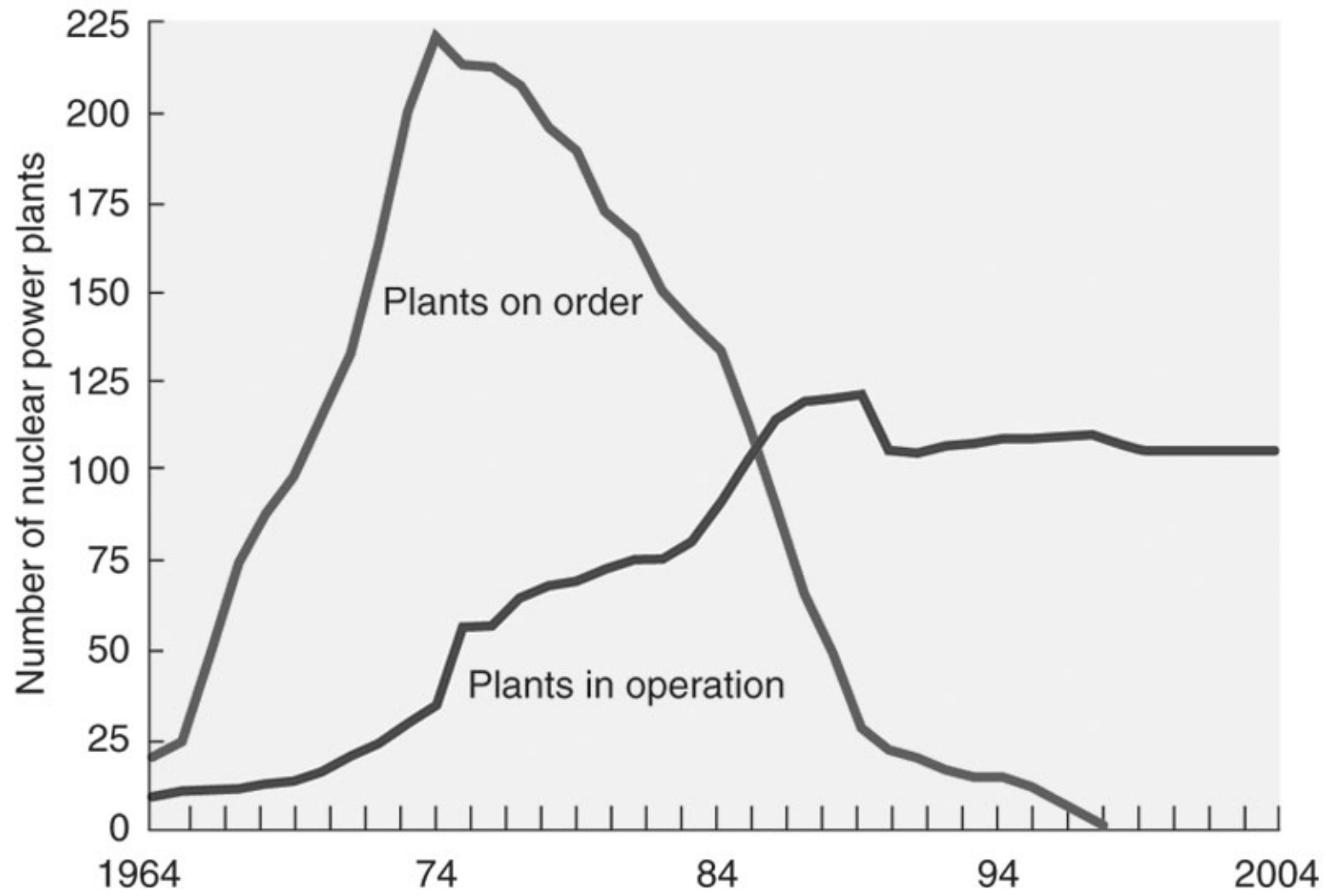
- In 1953, President Dwight Eisenhower gave his famous “Atoms for Peace” speech.
  - ❖ Nuclear-powered electrical generators would provide power “too cheap to meter.”
    - Between 1970 and 1974, American utilities ordered 140 new reactors for power plants.
    - But construction costs were high and there were safety fears.

# Nuclear Power

- After 1975, only 13 orders were placed for new nuclear reactors, and all of those were subsequently cancelled.
  - ❖ In all, 100 of 140 reactors on order in 1975 were cancelled.
    - Electricity from nuclear power plants was about half the price of coal in 1970, but twice as much in 1990.

# Nuclear Power Plant History

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# How Do Nuclear Reactors Work?

- Most commonly used fuel is  $\text{U}^{235}$ , a naturally occurring radioactive isotope of uranium.
  - Occurs naturally at 0.7% of uranium, but must be enriched to 3%
- Formed in cylindrical pellets (1.5 cm long) and stacked in hollow metal rods (4 m long)
  - ❖ About 100 rods are bundled together to make a fuel assembly.
    - Thousands of fuel assemblies bundled in reactor core

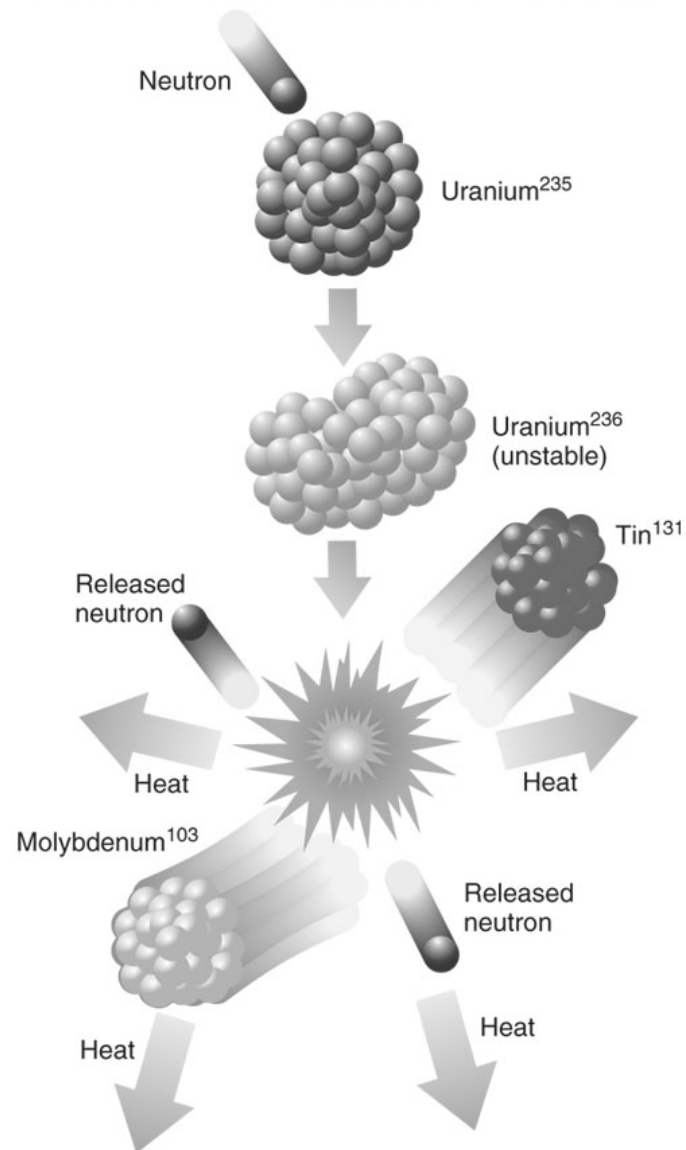
# How Do Nuclear Reactors Work?

- When struck by neutrons, radioactive uranium atoms undergo nuclear fission, releasing energy and more neutrons.
  - ❖ Triggers nuclear chain reaction



# Nuclear Fission

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# How Do Nuclear Reactors Work?

- Reaction is moderated in a power plant by neutron-absorbing cooling solution
  - ❖ In addition, control rods composed of neutron-absorbing material are inserted into spaces between fuel assemblies to control reaction rate.
    - Water or other coolant is circulated between the fuel rods to remove excess heat.
    - Greatest danger is a cooling system failure resulting in a meltdown

# There Are Many Kinds of Reactors

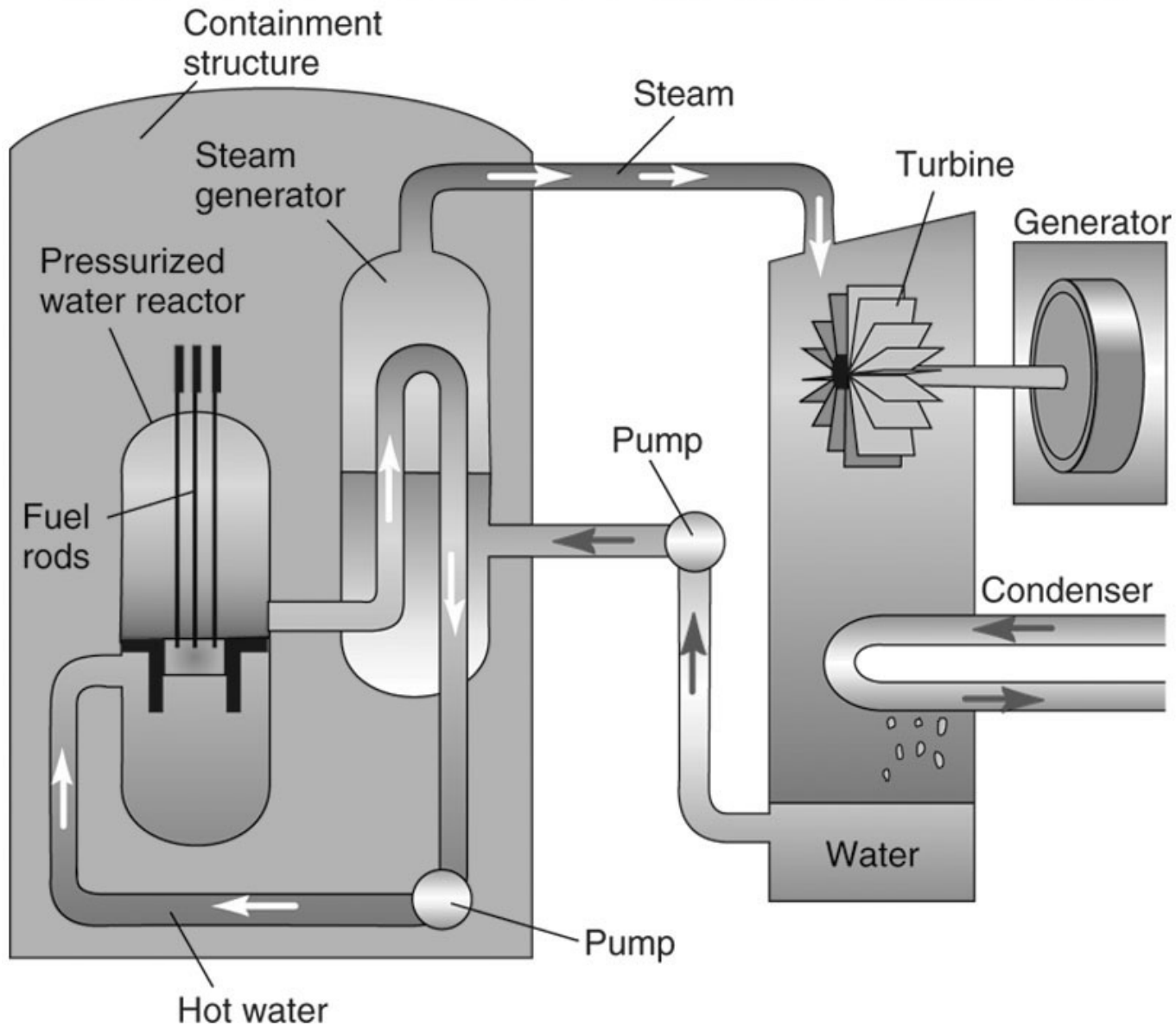
- Seventy percent of nuclear power plants are pressurized water reactors.
  - ❖ Water circulated through core to absorb heat from fuel rods
    - Pumped to steam generator where it heats a secondary loop
      - Steam from secondary loop drives high-speed turbine producing electricity.

# There Are Many Kinds of Reactors

- Both reactor vessel and steam generator are housed in a special containment building preventing radiation from escaping, and providing extra security in case of accidents.
  - ❖ Under normal operating conditions, a PWR releases very little radioactivity.

# PWR

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## There Are Many Kinds of Reactors

- Simpler, but more dangerous design, is a boiling water reactor.
  - ❖ Water from core boils to make steam, directly driving turbine generators
    - Highly radioactive water and steam leave containment structure and chances of accident are high.
- Graphite moderator reactors - operate with a solid moderator instead of a liquid
  - ❖ These are common in Britain, France and former Soviet countries.

# Kinds of Reactors

- Graphite moderator reactors have been involved in the biggest nuclear power disasters.
  - ❖ Chernobyl in Ukraine
  - ❖ Windscale in England
- The most famous accident in the U.S. happened at Three Mile Island near Harrisburg, PA. The reactor suffered a partial meltdown of the core.

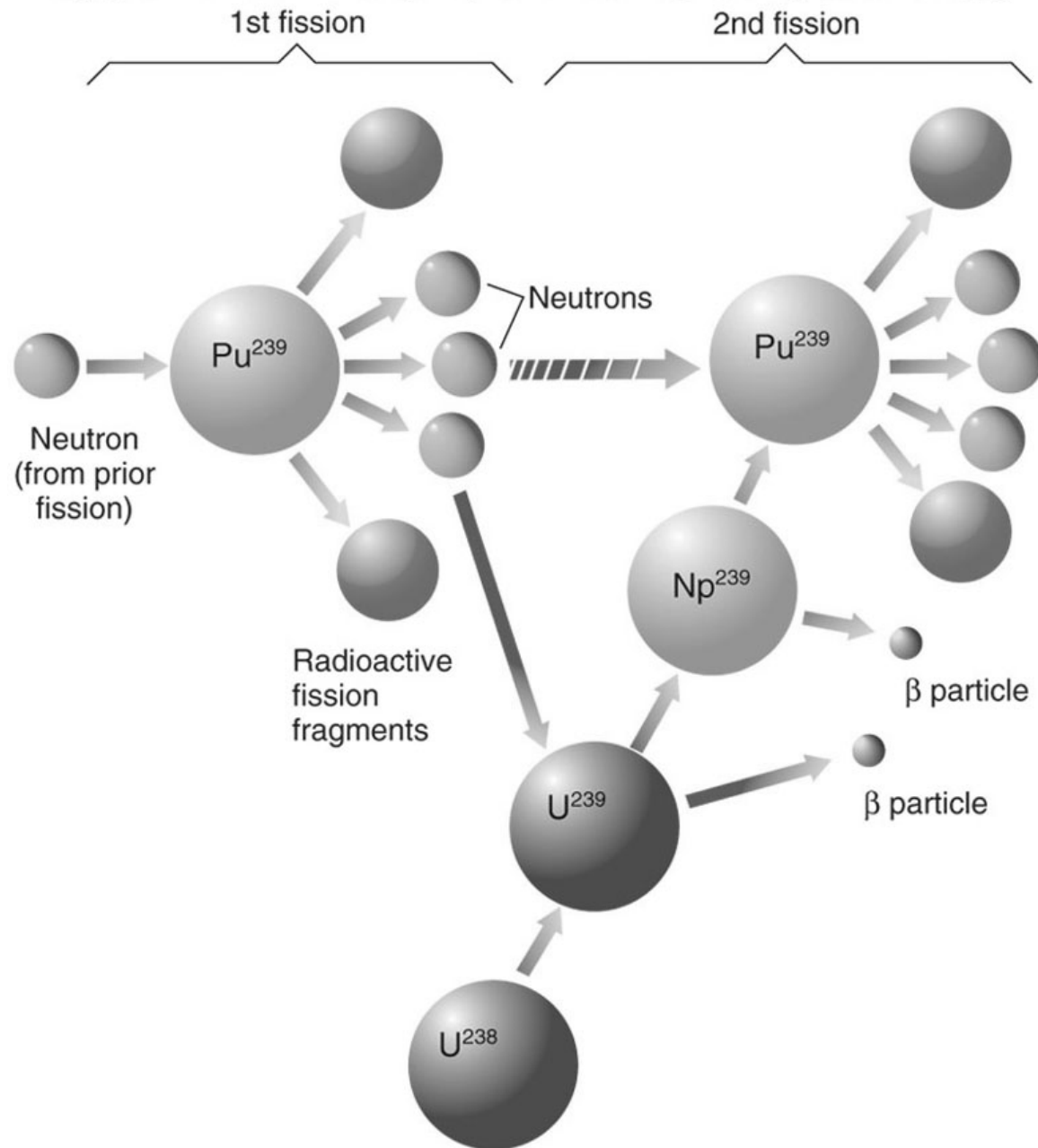
# Alternative Reactor Design

- High-Temperature, Gas-Cooled Reactors
  - ❖ Uranium encased in tiny ceramic-coated pellets and helium used as coolant.
  - ❖ If reactor core is kept small, it cannot generate enough heat to melt ceramic coating even if cooling is lost.



# Breeder Reactors

- Breeder reactors create fissionable plutonium and thorium isotopes from stable forms of uranium.
  - ❖ Uses plutonium reclaimed from spent fuel from conventional fission reactors as starting material.



# Breeder Reactor Drawbacks

- Reactor core must be at very high density, thus water cannot be used as coolant.
  - ❖ Liquid sodium is used instead. Liquid sodium is corrosive, burns with intense heat, and explodes on contact with water. A breeder reactor will self-destruct in a few seconds if coolant fails.
- Breeder reactors produce weapons grade plutonium as waste.

# We Lack Storage for Radioactive Wastes

- Until 1970, the U.S., Britain, France, and Japan disposed of radioactive waste in the ocean. Soviet Union seriously contaminated Arctic Ocean.
  - ❖ Production of 1,000 tons of uranium fuel typically generates 100,000 tons of tailings and 3.5 million liters of liquid waste.
    - There are now approximately 200 million tons of radioactive waste in piles around mines and processing plants in the U.S.

# We Lack Storage for Radioactive Wastes

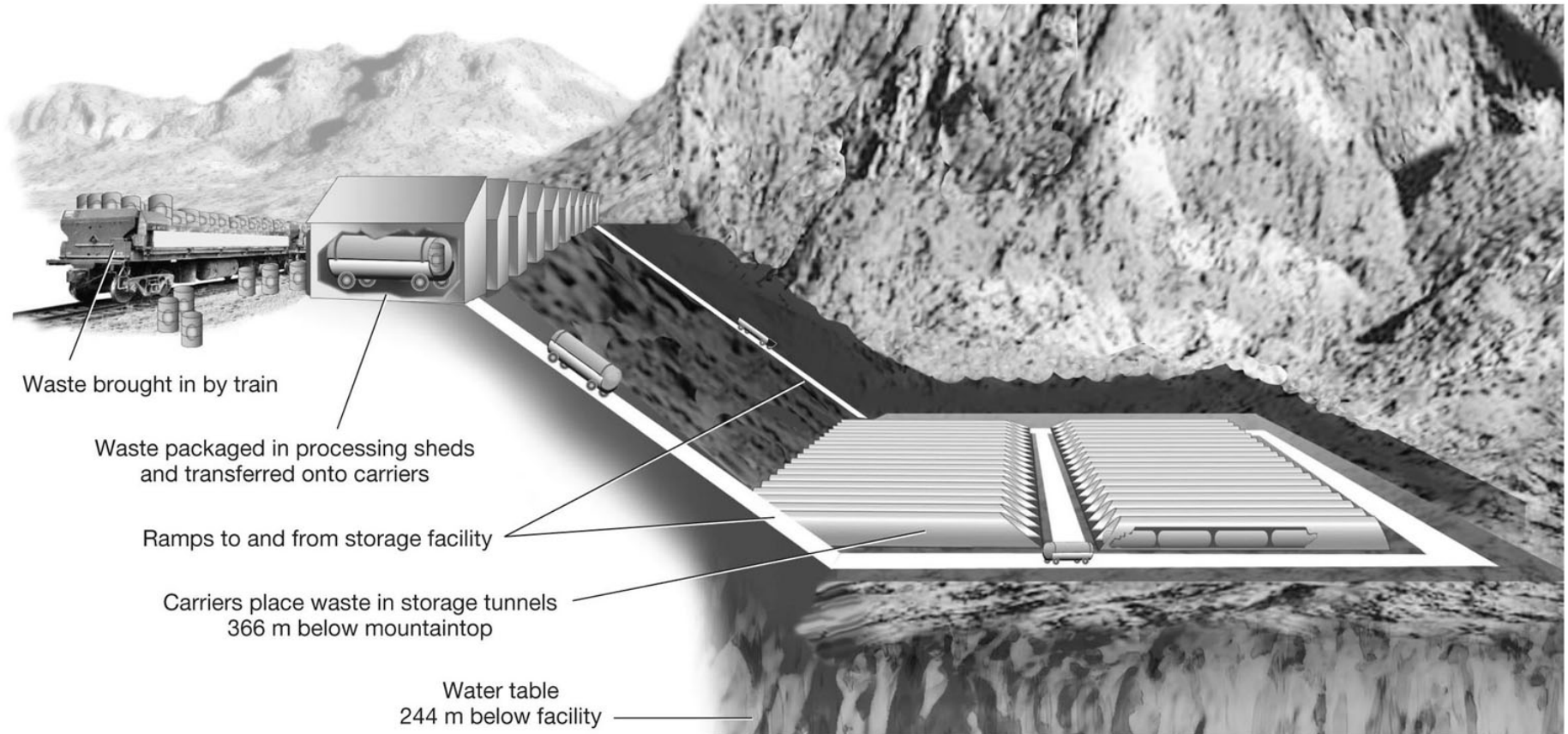
- About 100,000 tons of low-level waste (clothing, tools) and about 15,000 tons of high-level (spent-fuel) waste in the U.S.
  - ❖ For the past 20 years, spent fuel assemblies have been stored in deep water-filled pools at the power plants. (Designed to be temporary.)
    - Many internal pools are now filled and a number of plants are storing nuclear waste in metal dry casks outside.

# We Lack Storage for Radioactive Wastes

- U.S. Department of Energy announced plans to build a high-level waste repository near Yucca Mountain Nevada in 1987.
  - ❖ Radioactive waste would be buried
  - ❖ Facility may cost between \$10 and \$35 billion, and will not open until at least 2010
- Russia has offered to store nuclear waste from other countries at Mayak in Ural Mountains. An explosion there in 1957 made the area the most radioactive place on earth, so Russians feel it can't get much worse.

# Yucca Mountain Waste Depository

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# Decommissioning Old Nuclear Plants

- Most plants have only a 30 year operating life.
- Reactors must be disassembled and the parts removed by remote controlled robots. The debris must be stored as nuclear waste for thousands of years.
- Shipping contaminated items to a storage site is a problem as many states and countries refuse passage.
- Decommissioning all the U.S. reactors currently in use could cost between 200 billion and 1 trillion dollars.



# Changing Fortunes of Nuclear Power

- Public opinion has fluctuated over the years.
  - ❖ When Chernobyl exploded in 1985, less than one-third of Americans favored nuclear power.
    - Now, half of all Americans support nuclear-energy.
- Currently, 103 nuclear reactors produce about 20% of all electricity consumed in the U.S.

# Changing Fortunes

- With oil and gas prices soaring, many sectors are once again promoting nuclear reactors.
- Some prominent environmental conservationists are now promoting nuclear as a clean power source that doesn't emit greenhouse gases.
  - ❖ Over the past 50 years, the U.S. government has provided \$150 billion in nuclear subsidies, but less than \$5 billion to renewable energy research.
  - ❖ Where might we be now if the ratio had been reversed?

# Nuclear Fusion

- Nuclear Fusion - Energy released when two smaller atomic nuclei fuse into one large nucleus. Energy in sun, hydrogen bombs.
  - ❖ Temperatures must be raised to  $100,000,000^{\circ}\text{C}$  and pressure must reach several billion atmospheres.
    - Magnetic Confinement
    - Inertial Confinement
      - Despite 50 years and \$25 billion, fusion reactors have never produced more energy than they consume.

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